Crab cavity: operational scenarios and opics

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Motivation

The crab cavity prototype test has the following goal/milestone:

- Show that crab cavity can be installed and operated safely in the LHC.
- Find measurable proofs of a beneficial effect of the cavity on the luminosity.
- Test luminosity leveling.

Operation

The prototype test will use at the beginning few bunches and only after success full beam.

- Injection and ramp:
  - 0 voltage (RF loops on to maintain 0 energy in the cavity)
  - dephased (the cavity act like a dipole kicker)
  - detuned (the beam does not see it)
  - 2 cavity cancellation (easy to operate, double voltage)
- Collision: IR4 get anti-squeezed.
  - ramp (few tens of turns fulfill adiabaticity)
  - rephase (simulation to be done)
  - detuned (simulation to be done)
  - rephase (simulation to be done)

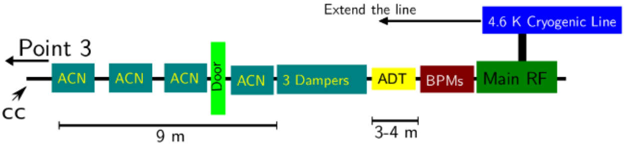
Failures scenarios beyond the prototype test with full beam

Power supply trip,
cavity quench,
single cavity trip,
coupler failure,
vacuum problems,
RF loops problems.

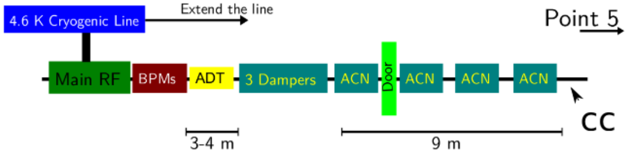
In KEK-B the beam is dumped, but experiments in KEK-B are under study to avoid the dump using a controlled ramp down.

IR4 Base line layout

Beam 1



Beam 2



Crab Voltage

$$V_{\mathrm{crab}} = \frac{2cE_0 \tan(\theta_c/2)}{\omega_{\mathrm{rf}}} \frac{\sin(\mu_x/2)}{\sqrt{\beta_{\mathrm{crab}}\beta^*}\cos(\psi^x_{\mathrm{cc}\to\mathrm{ip}} - \mu_x/2)}$$

E_0 is the beam energy,
$\theta_c = d_{\mathrm{sep}}\sqrt{\epsilon/\beta^*}$ is the crossing angle,
ω_{rf} is the crab cavity RF frequency,
β^* is the beta function at the IP
μ_x is the horizz. tune,

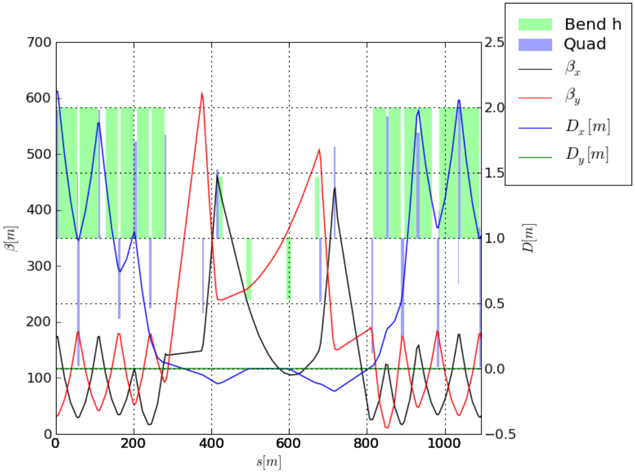
β_{crab} and $\psi^x_{\mathrm{cc}\to\mathrm{ip}}$ are the quantities to be optimized.

Crab optics

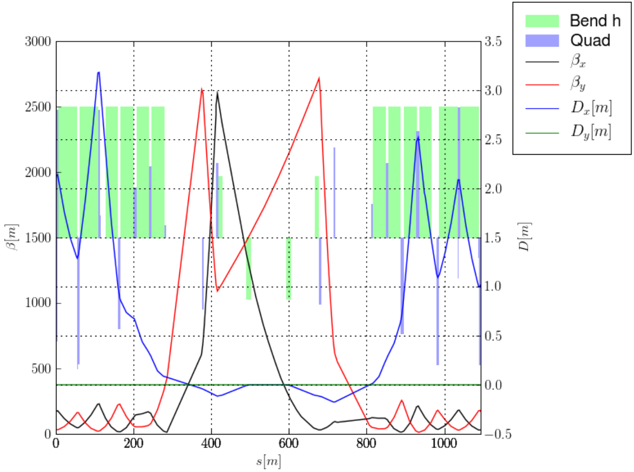
Phase 1 phase advances ($\psi^{x}_{cc\rightarrow ip}$):
Beam1 7.636,
Beam2 8.185.
Ideal are .655 and .155.

We keep the same phase advance. We assume that the IR4 optics can be changed at flat top in a similar way IR1 and IR5 are squeezed.
We allow three quadrupoles to change polarity which would require new bipolar power supplies. Studies avoiding new power supplies are on going.
The following optics and aperture are for Beam 1 only. Beam 2 studies are on going.

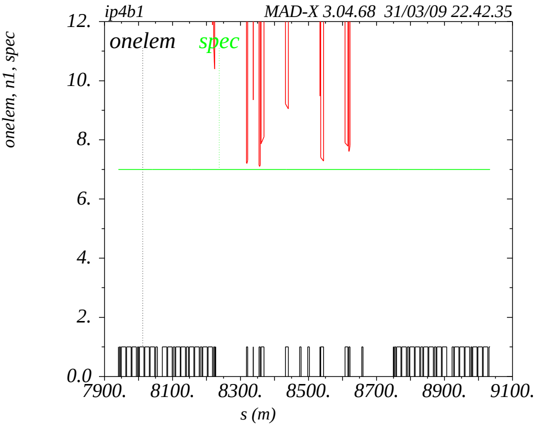
450TeV 200m optics



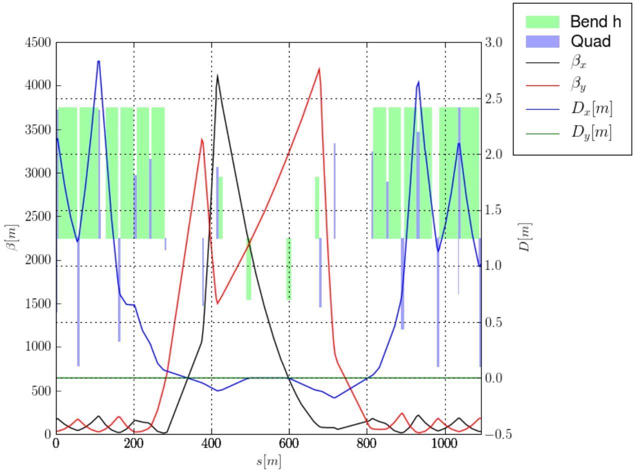
3TeV 1km optics



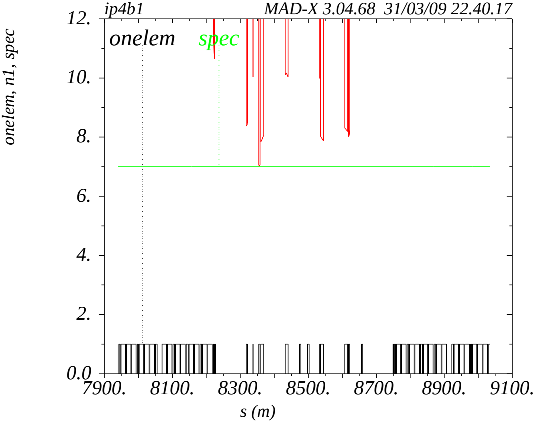
3TeV 1km optics



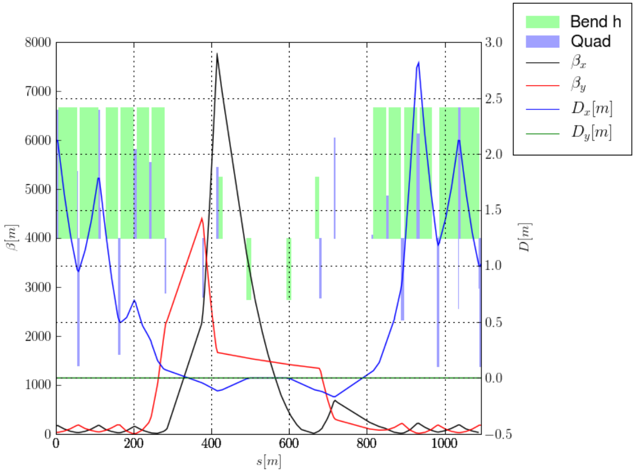
5TeV 2km optics



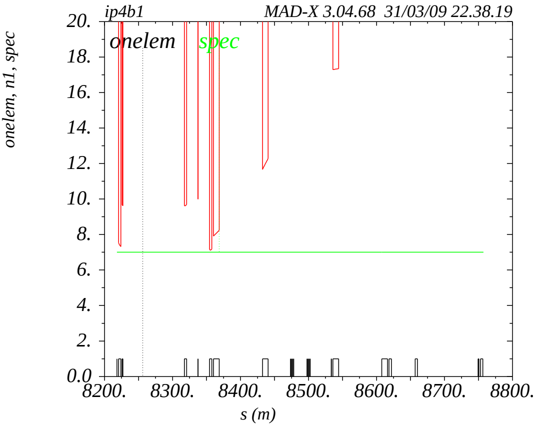
5TeV 2km optics



7TeV 3km optics



7TeV 3km optics



Crab luminosity

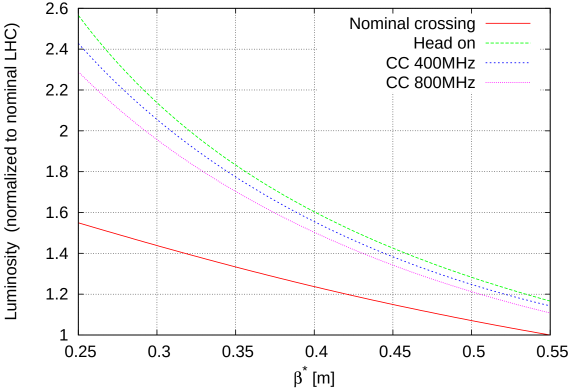
LHC luminosity can be approximated by:

$$\mathcal{L} = \mathcal{L}_{\mathrm{ho}} F_{\mathrm{geo}} \qquad \mathcal{L}_{\mathrm{ho}} = \frac{N_b^2 n_b f_{\mathrm{rev}}}{4\pi\epsilon\beta^*} \qquad F_{\mathrm{geo}} = 1/\sqrt{\left(1 + \frac{\sigma_z\theta_c}{2\sigma^*}\right)^2}$$

$$0 < \frac{2\sigma^*}{\sigma_z\theta_c} < F_{\mathrm{geo}} < 1$$

The crab beam luminosity is bounded between the head-on and crossing angle luminosity.
The crab luminosity increase cannot easily computed analytically because of the RF sinusoidal distortion, numerical will evaluation is used.

Crab luminosity



Max luminosity increase

Voltage	β_{crab}	β^*	$\theta_{crossing}$	Energy	$\mathcal{L}_{cr}/\mathcal{L}_{ho}$	$\mathcal{L}_{nocr}/\mathcal{L}_{ho}$	$\mathcal{L}_{cr}/\mathcal{L}_{nocr}$
5.5MV	3km	25cm	453urad	7TeV	0.86	0.55	1.56
4.6MV	3km	30cm	383urad	7TeV	0.88	0.62	1.40
2.5MV	3km	55cm	305urad	7TeV	0.91	0.82	1.10
1.5MV	2km	1m	268urad	5TeV	-	0.93	-
0.6MV	1km	3m	200urad	3TeV	-	0.99	-
0.1MV	200m	10m	282urad	450MeV	-	1	-

It assumes 800MHz cavity.
A 400MHz option for a phase-2 will further enhance this figure.

Future work for optics

Beam 2.
Squeeze procedure.
Evaluate effects on instrumentation.
Detailed beam simulation studies:

- Dynamic aperture,
- Beam-beam,
- Collimation,
- Halo and background,
- Tunability,
- Chromatic effects,
- Linear imperfection.

Future work for operational scenarios

Simulation for operational scenarios and for some failure scenarios
Experiments in KEK-B.
Removal program in the short technical shutdown.